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Great Basin Ecosystem Management Project

Bedrock Topography and Sediment Stratigraphy Analysis Using Near-Surface Seismic Techniques and Ground Penetrating Radar, Central Great Basin, Nevada

Final Report

Summary

Seismic data and ground penetrating radar (GPR) data were collected at 6 sites throughout the Central Great Basin. Data are used to determine the depth to bedrock, bedrock structure and stratigraphic variation in the near subsurface. Over 8 km of seismic profiles and over 70 GPR profiles were collected. Data indicate complex geometry of the sediment/bedrock interface at all meadow locations with the exception of Indian Creek, where the bedrock topography was relatively flat. In addition, the seismic and GPR data indicate that regions of sub-horizontal sedimentary units are interspersed with complex stratified units throughout all meadows, again the exception being Indian Creek. These zones of heterogeneity are likely representative of complex sediment infilling during side-valley alluvial fan activity or during valley-constricted flooding. Further interpretation of this geophysical data with correlated borehole information should further elucidate these interpretations.

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GREAT BASIN ECOSYSTEM MANAGEMENT PROJECT

Introduction

Seismic techniques have been successfully applied in one test meadow within the Central Great Basin in 2003 (Phase 1). The success of that study lends the use of the technique in other meadows around the region. The past use of ground penetrating radar (GPR) in stratigraphic studies (Matanuska Glacier, Baffin Island, Byron, NY), illustrates the high success rate of this technique in determining stratigraphic variability. Seismic profiles (both reflection and refraction) and GPR were collected in 6 sites around the Central Great Basin to assist with in-site hydrologic characterization by determining depth to bedrock, bedrock structure and stratigraphic variation. A total of over 8 km of seismic data and over 70 GPR profiles were collected over two summer field seasons. Details of the refraction tomography technique are not discussed here, but are outlined in Supplemental Report 2002-S01. Details of near-surface seismic reflection processing are outlined in Baker ("Processing Near-Surface Seismic Reflection Data: A Primer" 1999). Details of GPR data processing are outlined in Baker and Martinez ("Processing GPR Data for Stratigraphic Studies", *in press*).

Central Great Basin Site Locations

The six field sites (Kingston Canyon, Birch Creek, Big Creek, Indian Creek, Corcoran Canyon and Barley Creek) are located in the Central Great Basin region of Nevada, south of the town of Austin, Nevada, in the Toiyabe, Toquima and Moniter ranges (Figure 1).

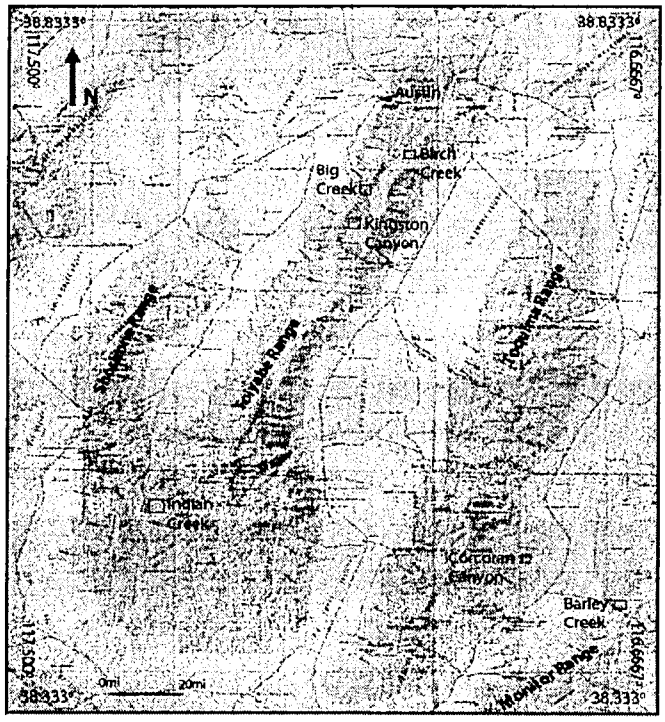

Figure 1: Location of six field sites from 2003-2005

Seismic Data Collection

The details of seismic data collection for Phase 1 (2003) are outlined in GBEM Geophysics Report 2004-01. Seismic data collection in 2004 consisted of profiles in 4 meadows. Data collection in 2005 consisted of profiles collected in 2 additional meadows and another profile in a previous meadow. The source used for all data collection is the Thunderbolt™ impact source. Data were recorded with a Geometrics 60-channel digital seismograph with 24-bit A/D conversion and Mark Products L40A 40 Hz geophones. Both seismic reflection and seismic refraction tomography were collected along the same profiles. Source spacing for these lines was 3 meters, and receiver spacing varied between 1 and 1.5 meters. Shots were stacked between 5-20 times with the Thunderbolt™, depending on the location of the source to the receiver set. This is to enhance the signal-to-noise ratio of the data. Several profiles in each spread involved moving the spread due to the length of the profile. All data were recorded for 512 ms and had a sampling interval of 0.125 ms. Profiles were arranged so that there was at least one profile down the axis of a meadow, and profiles at the downstream end of the meadows, as well as over any side-valley alluvial fans present.

Preliminary Results

Technique testing and optimization at similar geological settings (Lost River Range, Idaho; Unaweep Canyon, Colorado) indicated that refraction tomography results would be favorable at the Kingston Canyon test site. Additionally, the geometry of data collection for the profiles would allow for simultaneous processing of data as seismic reflection profiles if data quality were sufficiently high, allowing for high likely hood of success. Three near-surface seismic profiles were collected in the Kingston Meadow site in August 2003 to assist in site hydrologic characterization by determining depth to bedrock and bedrock structure. A total of approximately 1.3 km of data along three profiles was collected during a 4-day period using a field crew of 3-4 people. Details of the refraction tomography technique are not discussed here, but are outlined in Supplemental Report 2002-S01. Details of near-surface seismic reflection processing are outlined in Baker ("Processing Near-Surface Seismic Reflection Data: A Primer" 1999).

Kingston Meadow Site Location

The Kinston Meadow site is located in the Central Great Basin region of Nevada, south of the town of Austin, Nevada, in Kinston Canyon (Figure 2). The three profiles (03-01 through 03-03) were collected within the site (Figure 2).

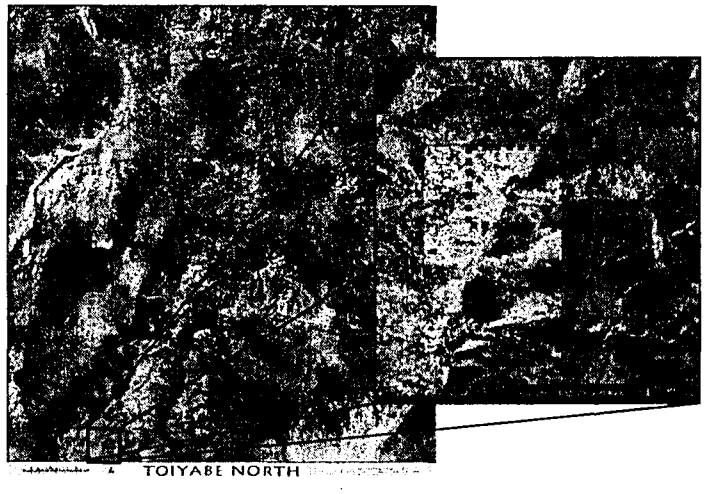

Figure 2. Location map of the Kinston Meadow complex.

Phase I Seismic Profile Locations and Data Acquisition

The three profiles (Figure 3) were laid out to provide initial estimations of bedrock depth and structure in the tributary valley (Profile 03-01) and the main valley of the Kinston Meadow (Profiles 03-02 and 03-03). Profiles 03-01 and 03-03 were collected with a receiver (geophone) spacing of 1.5 m, and Profile 03-02 was collected with a receive spacing of 1 m (to optimize coverage versus profile length). The source (shot) spacing for all three profiles was 6 m.

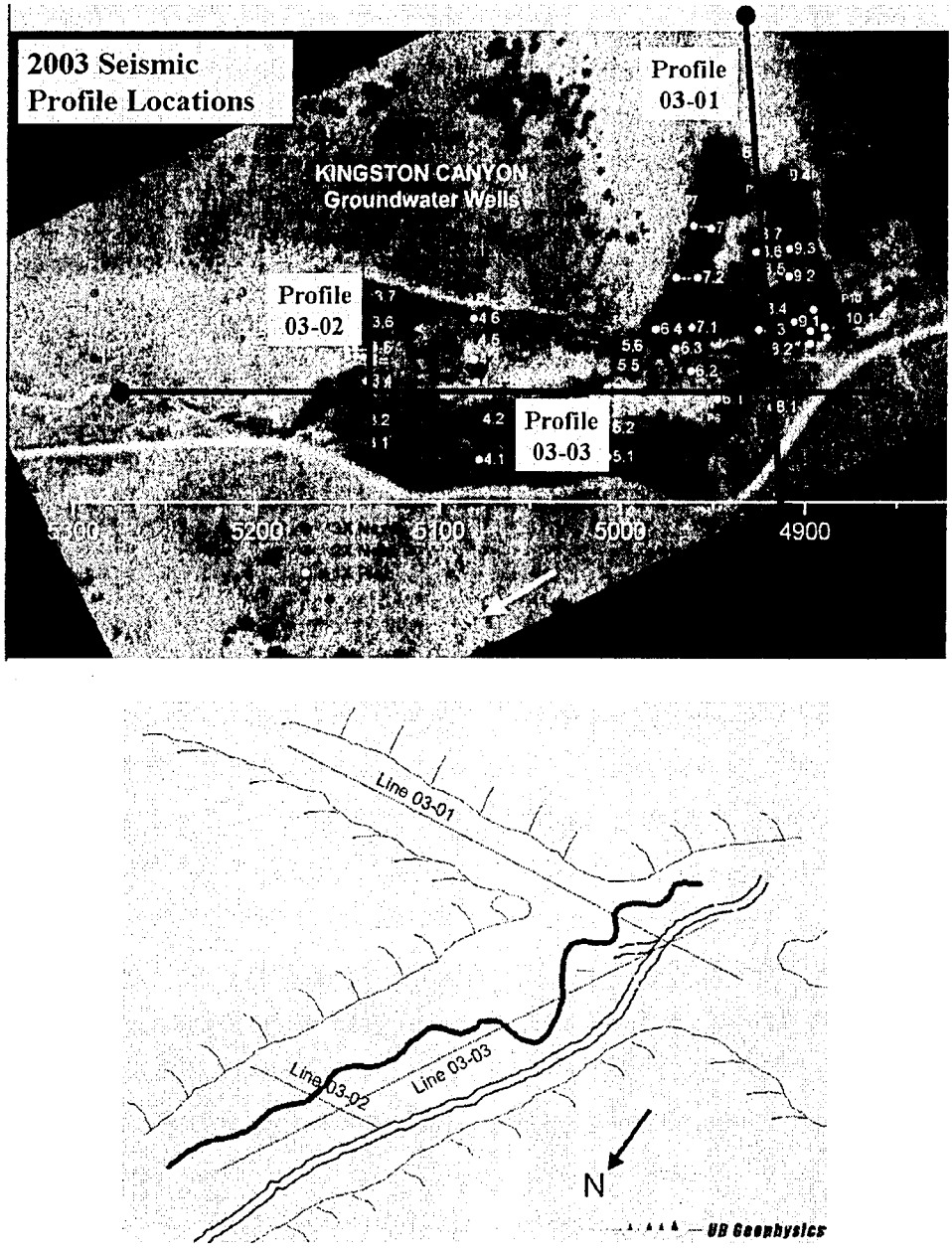

Figure 3. Location map (top) of the Kinston Meadow seismic profile locations superimposed on the groundwater well locations, and schematic representation (bottom) of the same profile locations.

At previous sites in the Basin-and-Range of the western U.S. having similar geology, several new sources have been tested (2001; 2003) and a log-splitter/post-hole device was ultimately used for all profiles. This device (product name: Thunderbolt) yields highly repeatable results. Between 5 and 20 blows of the Thunderbolt™ were stacked at each shot point to enhance the signal-to-noise ratio (S/N) of the data. Data from receivers were recorded using a Geometrics 60-channel digital seismograph with 24-bit A/D conversion. In Profile 03-02, the receiver spread was not moved. In Profiles 03-01 and 03-03 the spread was moved once to accommodate the longer profiles. Data were recorded for 512 ms using a sampling interval of 0.125 ms.

GPR Data Collection

GPR data were collected in 2005, in the same 6 meadows as the seismic data. The data were collected using a Sensors & Software Pulse Ekko 100A GPR unit, with 50, 100 and 200 MHz antenna. Antenna separation is 2 meters for the 50 MHz, 1 meter for the 100 MHz and 0.5 meters for the 200 MHz. The step size is 0.25 for the 50 and 100 MHz antenna and 0.10 meters for the 200 MHz antenna. For more efficient data collection, 100 and 200 MHz antenna were mounted on particle board "sleds" and towed behind the user at a constant rate to correct for aliasing of the data. Common mid-point data were also collected several times throughout each meadow to help with the validation of the direct wave velocity. Profiles were arranged to run between boreholes for better calibration with the known lithologic units. Profiles were also arranged to run across the width of the meadow to see if it was possible to image the side walls of the valley beneath the meadow.

Phase 1 Results

The details of the results of Phase 1 are again outlined in the GBEM Geophysics Report 2004-01. The results of this study were very positive for the use of the seismic techniques to analyze bedrock geometry and bedrock structure. The use of both the seismic reflection and seismic refraction led to well constrained data. The results of the three profiles are shown in Figure 4. The refraction tomography velocity fields that result from the inversion process are interpreted to relate to three main layers, constrained by the reflection data. The shallowest layer (that is sometimes absent) has a velocity of 700 m/s (pink layer). The next two layers are at 1500 (orange layer) and 3400 (green layer) m/s. The green lines are bedrock reflections from the seismic reflection data.

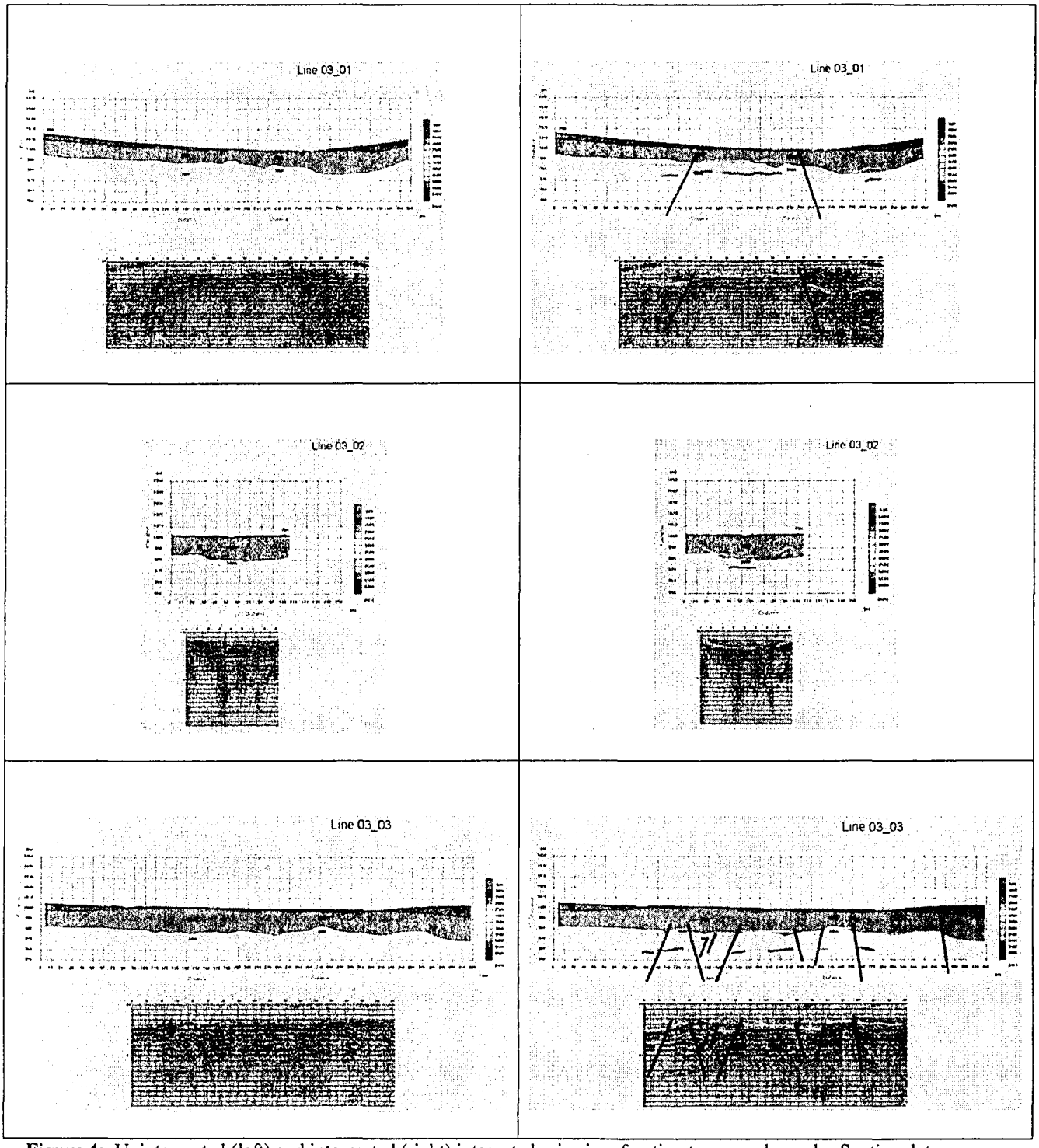

Figure 4: Uninterpreted (left) and interpreted (right) integrated seismic refraction tomography and reflection data from Profile 03-01 (top), Profile 03-02 (middle), and Profile 03-03 (bottom). Note the good agreement between the seismic reflection interpretations superimposed upon the refraction tomography data. The green layer represents the top of the bedrock; the red layer represents an internal bedrock interface.

Seismic Reflection Data

Analyses of the data indicate that the seismic *p*-wave velocities broke out into three distinct ranges: 700 m/s direct wave (often found only in the first several receivers) indicative of unsaturated, unconsolidated sediments; 1500 m/s (often the direct wave rather than a refraction) indicative of saturated, unconsolidated sediment; and 3400 m/s refraction, indicative of bedrock (Figure 5).

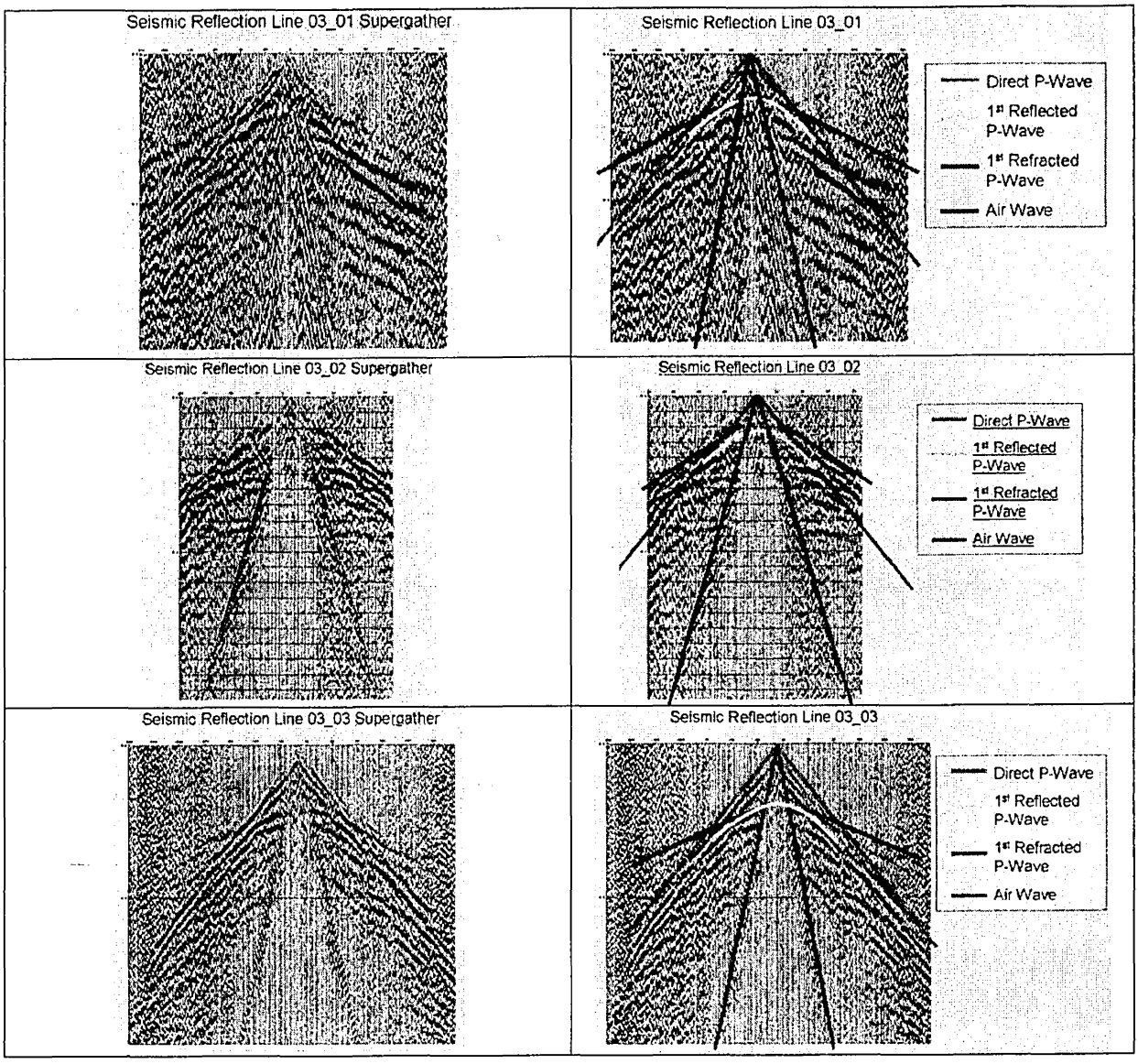

Figure 5. Uninterpreted (left) and interpreted (right) supergathers of seismic data from Profile 03-01 (top), Profile 03-02 (middle), and Profile 03-03 (bottom). Analysis of the direct and refracted arrivals determined the layer velocities shown in Fig. 3. The vertical scale is travel time in seconds, and the horizontal scale is source-to-receiver offset in meters.

Phase 2 Seismic Results

Seismic refraction results from 2004 and 2005 show promising correlation with data from 2003. Figure 6 shows an example of a refraction tomogram from 2004 which exhibits similar characteristics to the 2003 data.

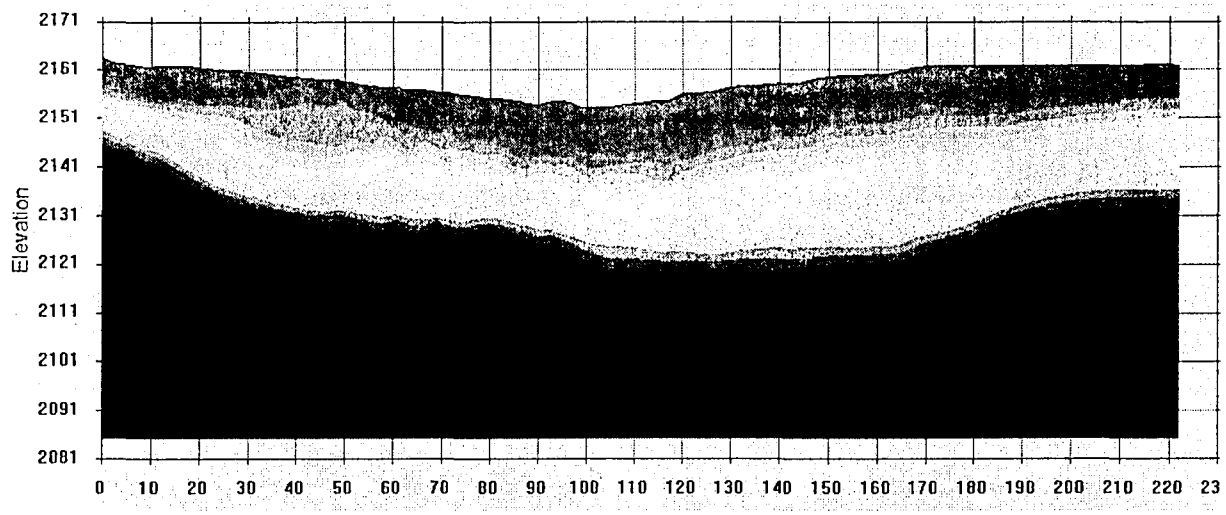

Figure 6: Example of a refraction tomogram from Big Creek (2004). The horizontal scale is distance in meters and the vertical scale is elevation in meters. Note the thickness of the slow velocity layer (pinks and reds) and the shape of the higher velocity boundary (dark green and blue).

The higher velocity layer may correlate to the bedrock surface, however this assumption cannot be validated until the seismic reflection data processing is completed for this meadow to confirm velocities. Figure 7 shows an example of refraction tomogram with a smaller low velocity layer from a different meadow.

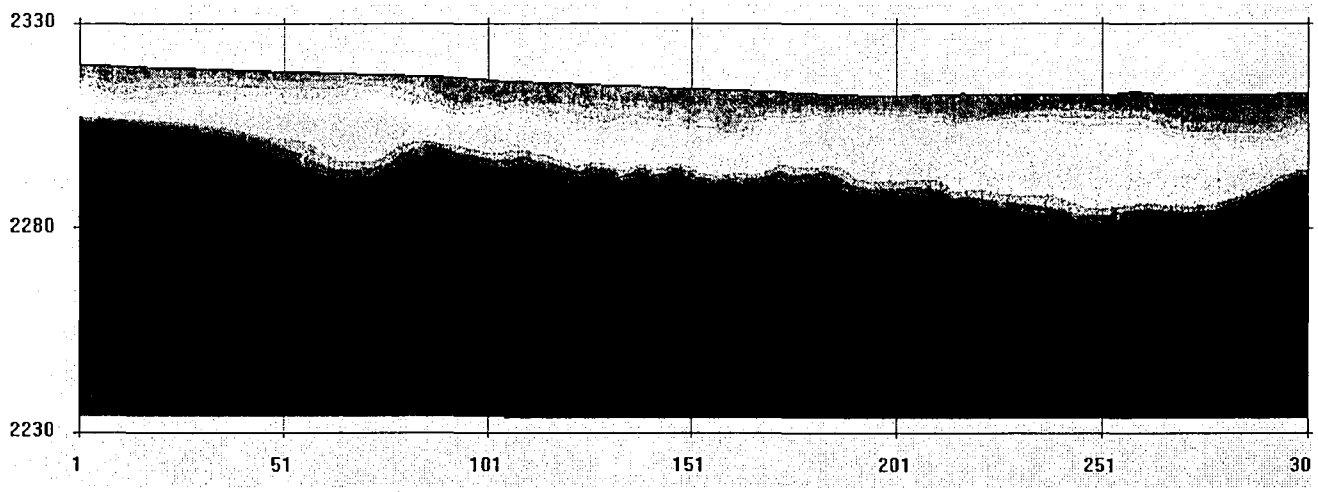

Figure 7: Example of a tomogram from Kingston Canyon (2004). The horizontal scale is distance in meters and the vertical scale is elevation in meters. Note the change in the higher velocity boundary from the tomogram in Figure 3.

Phase 2 Ground Penetrating Radar Results

The results from the GPR show good correlation with the known lithology data. GPR data were entered into Rockworks 2004 with borehole information and plotted in the same coordinate system to correlate reflectors with lithology in boreholes. All the profiles and boreholes are then imaged in RockPlot 3-D to allow for the rotation and movement of the image for better analysis of the reflectors from all angles. Figure 8 shows an example of the distribution of profiles and boreholes in 1 meadow complex.

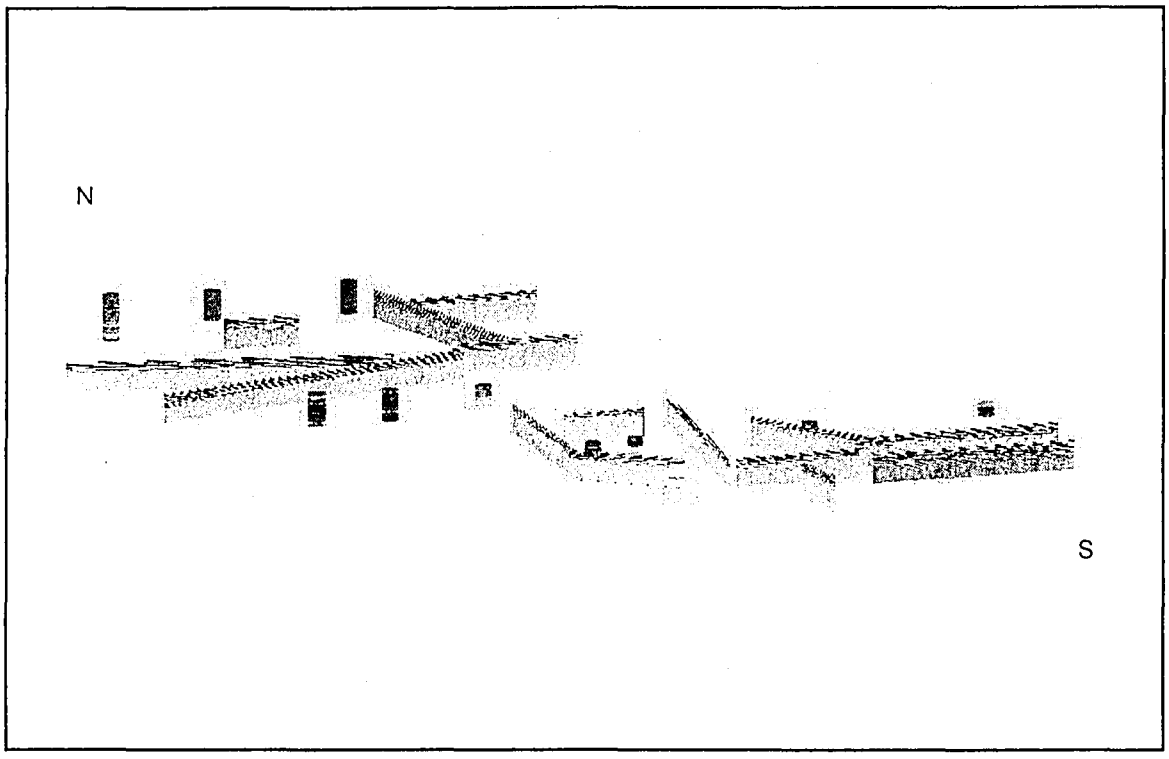

Figure 8: Distribution of GPR profiles and boreholes in Kingston Canyon

The lithology in most of the meadows is very complex, so it is hard to extrapolate lithologic surfaces using reflectors, however it is possible to identify areas where the reflectors exhibit chaotic or lateral characteristics. Figure 9 shows an example of a profile in a meadow which exhibits very horizontal reflectors, with good lateral continuity.

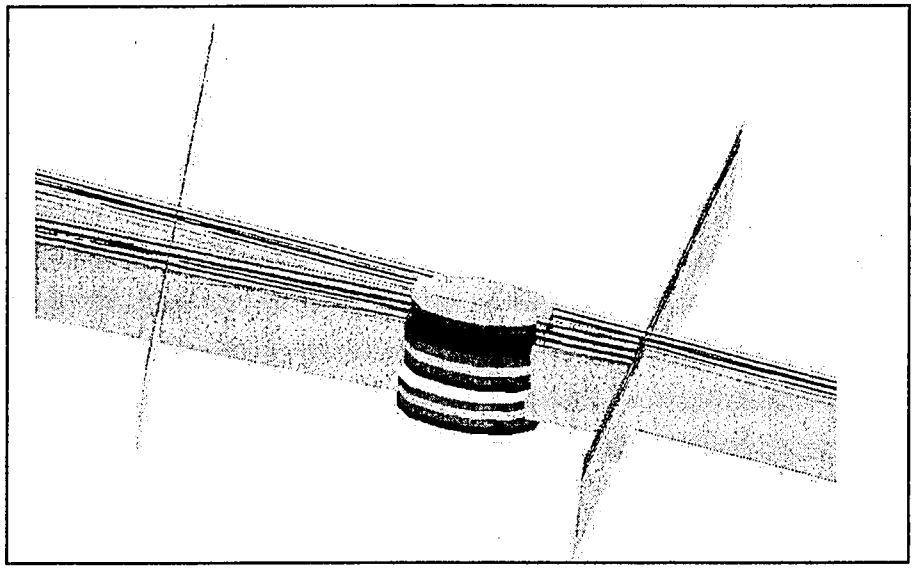

Figure 9: Indian Creek GPR results correlated with borehole information. This meadow shows good horizontal reflectors of sediments, with little chaos in the layers.

Some meadows exhibit more complex reflectors along the profiles, indicating a zone of chaos within the sediment. Tracing the lateral continuity of these layers may be more difficult, therefore right now the profiles are simply broken down into zones of complex reflectors and horizontal reflectors. Figure 10 shows an example of a meadow with more complex reflectors.

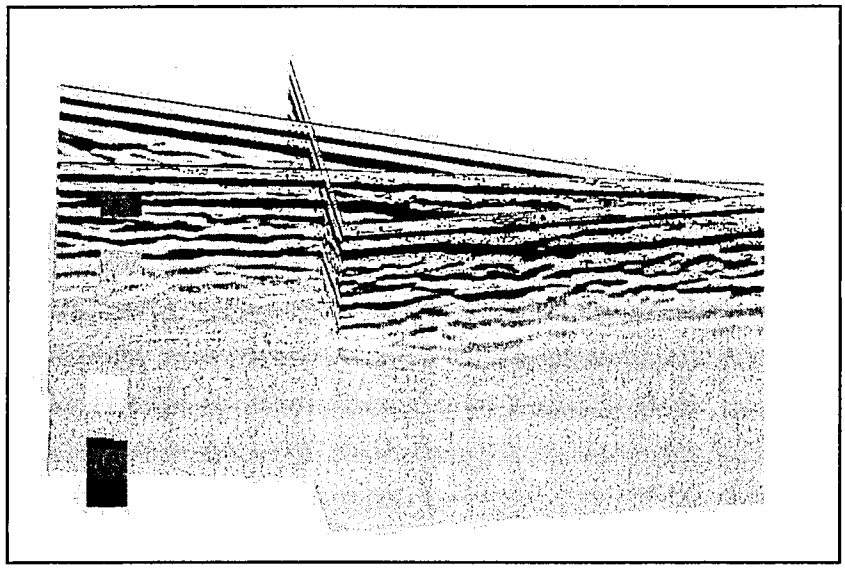

Figure 10: Big Creek GPR data correlated with borehole information. These reflectors exhibit a clear lack of lateral continuity, with reflections truncated or cross-cut. This would be classified as a complex system of reflectors with almost no horizontal layering

Summary of Data (Phase II)

Spring 2004
A site visit was be made to the Kingston meadow research site in May/June 2004 to (1) select depth to bedrock b/t P3 & P4 profiles and optimize for shallowest bedrock for boreholes to be drilled, and (2) finalize bedrock mapping in and around Kingston meadow.

Summer 2004
Seismic profiles of the depth to bedrock and bedrock structures were collected from alluvial fan systems within the study area that either do or do not support meadow ecosystems (dry vs. wet meadow sites). These data will be used to test the hypotheses that the occurrence of elevated ground water and, thus, meadow ecosystems are a function of (1) elevated bedrock (bedrock highs) behind the alluvial fans, or (2) a change in sediment characteristics towards finer soil textures that are more restrictive to downstream subsurface flow.

Kingston Downstream Dry Meadow Site

- 3 long-valley seismic profiles, 1 cross-valley seismic profile (borehole at intersection)

Big Creek Wet Meadow

- 2 long-valley seismic profiles

Big Creek/Corral Downstream Dry Meadow

- 2 long-valley seismic profiles

Indian Creek Wet Meadow

- 2 long-valley seismic profiles (contingency "bedrock soundings") if boreholes do not encounter bedrock

Birch Creek Wet Meadow

- 5 long-valley seismic profiles and cross profiles near fan/constriction

Plans for Future Work

Preliminary results from Buffalo Project Phase I (*see* Report 2004-01) indicate a high degree of success in using seismic refraction tomography/reflection data to determine depth to bedrock and bedrock structure in perched wetlands in the central Great Basin. Additionally, results from Buffalo Project Phase II (this report: Report 2005-01) support and expand on the results found in Buffalo Project Phase I. The potential tasks for 2005-2006 are presented below:

Fall/Winter 2005
Approximately 15 additional seismic profiles (about 200-m long each) were collected from alluvial fan systems within the study area in regions to be determined based on existing data gaps in the Phase I and Phase II data. These data will be incorporated into the Phase I and Phase II results to test the hypotheses that the occurrence of elevated ground water and, thus, meadow ecosystems are a function of (1) elevated bedrock (bedrock highs) behind the alluvial fans, or (2)

a change in sediment characteristics towards finer soil textures that are more restrictive to downstream subsurface flow.

In addition to the added seismic profiles, ground penetrating radar (GPR) data were collected to examine the shallow (upper 10 m) stratigraphy in several of the accessible meadows. The GPR will allow for lateral extrapolation of known borehole information into broader regions of the various meadow complexes. Several antenna frequencies (200, 100 and 50 MHz) were used to balance depth of penetration with resolution. The GPR profiles were run coincident with all seismic profiles where possible, and addition profiles will be collected between existing boreholes.

Both sets of data (seismic and GPR) will be processed and interpreted. These will be incorporated using the same RockWare™ software that other investigators have used to allow for ease of data sharing and transfer. The data from summer 2005 will be incorporated into Phase I & II data as well as other data from collaborating researchers.

Spring 2006
Finalize data analysis and interpretation. Work on project Report and peer-reviewed scientific publications.